THE HEREDITARY TENDENCY TO TWINNING, WITH SOME OBSERVATIONS CONCERNING THE THEORY OF HEREDITY GENERALLY

PART I

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HEREDITY, which is a subject of the deepest interest to metaphysicians, statesmen, and social reformers alike, and attracts daily more and more attention, implies the handing on from generation to generation, from parent to offspring, of specific and particulate characteristics, and it operates so constantly and so generally in the organic world under natural conditions, that we are fully warranted in affirming that "like begets like." With the truth of this axiom we are all in fact so thoroughly imbued, that without pausing to think whether it is or is not compatible with the much-vaunted doctrine regarding the origin of species, we feel confident, that not only the higher but all the lower animals and even the micro-organisms breed, and will continue to breed, true. On hatching the egg of a domestic hen we should indeed be surprised if there stepped forth life in any other form than that of a chick, and we should have good reason to be discomposed, if, on incubating pure cultures of the tubercle bacillus, we obtained any other micro-organism than that which is pathogonomic of tubercle. If, moreover, it were not for the inflexible ruling of heredity in the case of marine and fresh-water animals, where the ova and spermatozoa of the majority are strewn broadcast in the waters, and are afforded every facility for contracting irregular alliances, chaos would reign supreme and biological science would vanish into thin air.

At one time it very naturally was expected that hybridisation would throw much valuable light on many of the problems connected with heredity, but unfortunately experiments undertaken with this object are so seriously handicapped by sexuality, that the results obtained by crossing animals of distantly as well as nearly allied species have neither been satisfactory nor encouraging. The specific influence of sex is never a fixed quantity, and it stamps itself on so many structures besides those immediately concerned with reproduction, that, in crossing species, it is impossible to conjecture how sexuality may disport itself, and in what manner it may inhibit, or stop tendencies. At times, it even behaves so remarkably, that we are now and again confronted with what is known as unilateral hybridity, that state in which the ova of a species designated as A can be fertilised by the spermatozoa of another species termed B, but where, for some unknown reason, fertilisation in the inverse order cannot be effected, because the ova of B refuse to commingle with the spermatozoa of A. Again, hybridity in man even, where we have three distinct races, the white or Caucasian, the yellow or Mongolian, and the black or Ethiopian, furnishes us practically with no material which is of any real service to us in our study of heredity, and yet the characteristics of these races are very pronounced. Nowhere in human hybridity do we note any evidence of fixity or certainty of representation of the father or the mother. According to Klaproth the crossing of a Caucasian with a Mongolian gives offspring with a preponderance always of Mongolian qualities no matter whether the Mongolian is the father or the mother, but Levaillant on the other hand states that the crossing of a Caucasian with a Hottentot produces offspring which exhibit invariably a preponderance of those qualities, physical as well as mental, which characterise the race to which the father belongs.

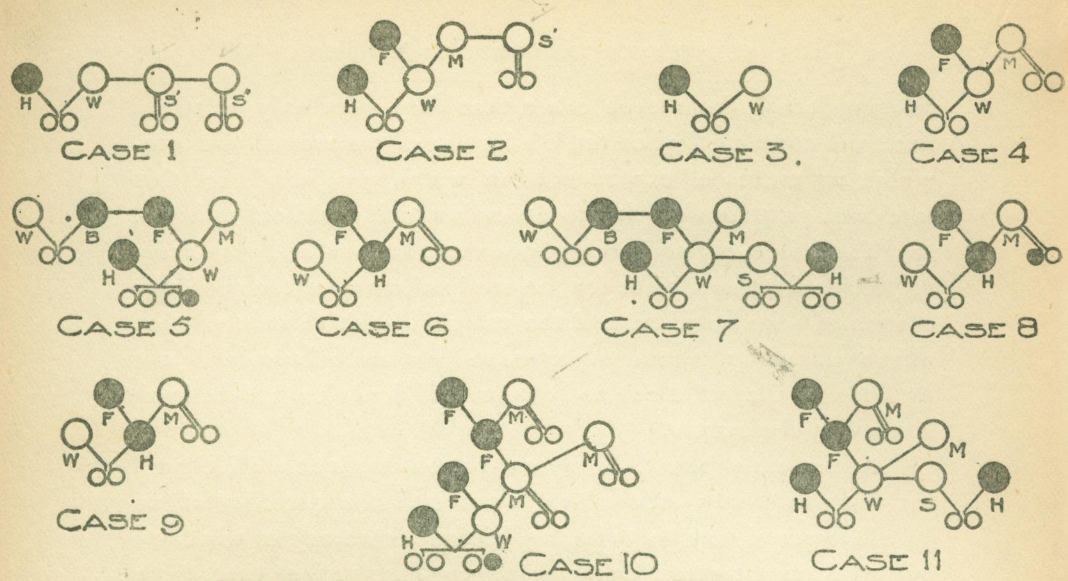
Furthermore, the phenomenon known as alternation of generations, the condition in which there is a regular alternation of sexual and asexual broods, and where the offspring is not only unlike, but sometimes extremely unlike the parents, although it does not contravene the principles of heredity, yet it, too, increases rather than lessens our difficulty in interpreting the subtle and devious workings of this force. Take, for example, the remarkable behaviour of the tapeworm *Taenia solium*. The generations of this parasite differ in every respect so considerably from each other that they were only definitely fixed and correlated when the life-history of the animal was completed by means of experiments in which proglottides of this intestinal parasite were fed to animals which could act as hosts.

There is every probability, however, that twinning is likely to prove a fruitful subject for the study of many of the problems connected with heredity, and the valuable light thrown on that phenomenon by recent experiments on animals carried out by Driesch, Herbst, Loeb and others, will doubtless arouse fresh interest in the matter.

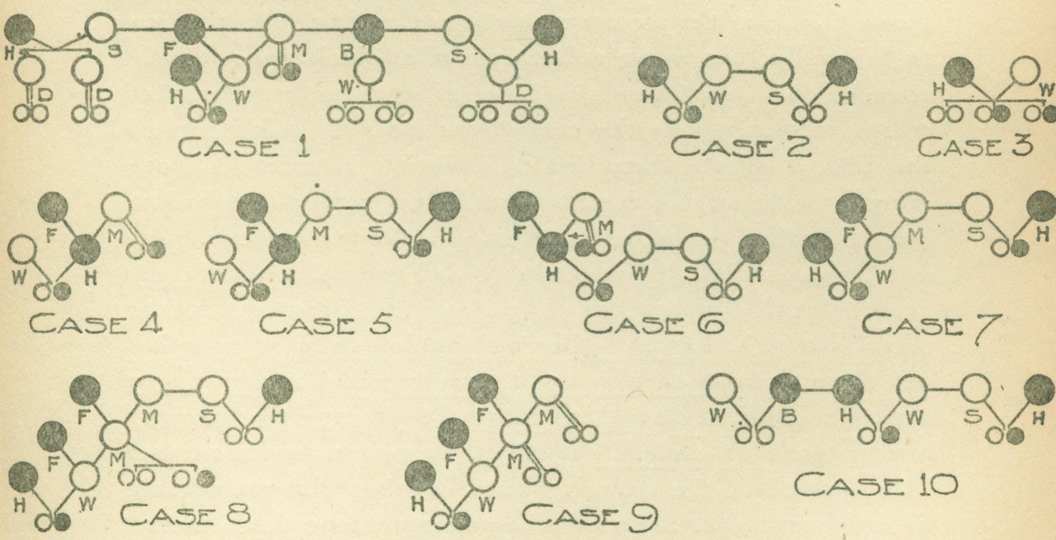
At an early period of my out-patient work at the Hospital for Women I was induced to investigate the question of an hereditary tendency to twinning because, contrary to what one expected, it appeared from desultory observation that both directly and indirectly the male played not infrequently an important part in the causation of twins. A direct action of the spermatozoon in the process seems at first a difficult proposition to believe in, but as we reflect upon what obtains every day in some of the lower animals it becomes more and more easy of comprehension. Take the case of the Bee. In this insect all the fertilised eggs produce females, whilst all the unfertilised ova bring forth males, and these males, although they have had no immediate male parent, nevertheless generate spermatozoa.

On scrutinising my hospital records I learnt that out of every two thousand five hundred out-patients that I saw twenty-four on an average had once or oftener given birth to twins, and that out of any twenty-four group thus aggregated nearly ninety per cent. furnished me with a history of twinning either amongst their own or their husband's relatives. In a diagrammatic manner I have sketched the twinning histories taken from one of these twenty-four groups. So far as an hereditary tendency in the matter is concerned the diagrams speak for themselves for it will be observed that in only three of the cases did I fail to obtain any family history bearing on the question, and I am disposed to think that if those three patients had only had a more intimate knowledge of their own or their husband's relatives my statistical evidence of the phenomenon would have been still more complete. See Figs. 1, 2, 3.

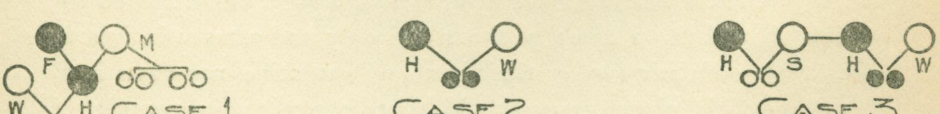
FEMALE CO-TWINS SUB-GROUP I



MALE AND FEMALE CO-TWINS SUB-GROUP II



MALE CO-TWINS SUB-GROUP III



H = HUSBAND
W = WIFE
F = FATHER
M = MOTHER
B = BROTHER
S = SISTER
D = DAUGHTER
SMALL CIRCLES REPRESENT TWINS

These three divisions, constituting one group, furnish us altogether with twenty-eight sets of twins, for one patient had borne twins on three occasions, whilst two others had each had twins twice. The co-twins in thirteen instances are of opposite sex; in twelve they are females; but in three only are they males. In all we have twenty-eight confinements yielding thirty-seven females and nineteen males, that is, these births augmented the population in the proportion of two females to every male. This, it may be noted, is fairly constantly the relative relationship of female to male births as a result of twin conceptions, and I would incidentally remark that a very similar state of affairs obtains in such uniparous animals as the mare, the cow and the sheep when twins are born to them. This which is undoubtedly a noteworthy fact, remains to be interpreted.

If we take the European countries and compute the legitimate and illegitimate births separately or together of any of them, we find that the various populations are as a rule pretty uniformly augmented at the rate of about one hundred and four males to every one hundred females. In all European countries in fact there is an excess of male over female births. In England and Wales, for example, during the year 1907 the total number of male and female legitimate births were respectively 449,213 and 430,640 and the total number of male and female illegitimate births were 18,515 and 17,674 respectively, or in each case proportionally about 4 per cent. more males than females. Had it been possible to estimate approximately the number of male and female children respectively produced by multiple births and these had been deducted from the aforesaid figures, then the percentage of male single births in excess of female single births would have been still higher. Now the marked difference in the nature of the addition to all European populations which results from multiple as distinct from single births depends upon the fact that in the case of twin births—the commonest variety of multiple birth—the co-twins are with almost equal frequency either bi-female or male and female: extremely rarely they are bi-male. The marked disparity which is noted in the relative frequency of co-twin female and co-twin male births must of course be due to some well-regulated train of events, but of the nature of these we are as ignorant as we are of those influences which play an all-important *rôle* in maintaining throughout the universe that varied numerical relationship of male to female births which is such an astounding phenomenon.

Take the Tadpole. In the case of this animal the female births largely exceed the male births : according to Pfluger the relative proportions are about thirteen males to every one hundred females. So too in some animals which reproduce parthenogenetically there is great disparity in the relative proportions of male to female births. In the Crustacean Artemia, for instance, males make their appearance only now and again.

In the matter of twinning I have come to the conclusion that the tendency to this phenomenon may directly and indirectly be inherited and transmitted about equally by the two sexes. There is presumptive evidence, however, that a stronger inherited influence is necessary for the production of co-twins of opposite sex than for the production of female co-twins, and that a very decided prepotency on the paternal side is requisite for the production of co-twin males.

In man and the majority of animals and plants reproduction is effected by the union of two germinal elements, one a sperm cell derived from the male parent, and the other an egg cell derived from the mother, and as each of these cells carries with it the promise and potency of any offspring which may be begotten of them, it is imperative that we should withou trespassing unduly into the domain of embryology review briefly the structure and demeanour of these cells as they reach maturity, and recall to mind the phenomenal changes which take place in the egg-cell when and shortly after conjugation is effected.

The ovum itself is usually microscopic, but the sperm cell is even still more minute. The latter is, as a rule, many thousand times smaller than the former, and as we contemplate these facts we very naturally find it exceedingly difficult to comprehend how such infinitesimal objects carry and transmit the multitude of ancestral and parental characteristics which they do.

Since the discovery of radium, however, our conception of atoms has been very materially supplemented and extended, and it is now quite possible to convince anyone that an atom has indeed a veritable existence, and is no longer the hypothetical thing it at one time was by many supposed to be. Without hesitation we can accept the statement that the one-three-thousand-millionth part of a grain of radium is easily recognisable, and to all and sundry it may be demonstrated ocularly that half a grain of bromide of radium, which is made up of fifty million billion separate atoms, gives off five thousand million of its α particles every second. With the wonderful little instrument devised by Sir William Crookes, and named the spinthariscope, we are all familiar, and we learn that the needle of this instrument, because it has merely touched a spot where radium has been, belches forth α particles incessantly, and will continue to do so for an indefinite length of time. Radium appears in fact to be surfeited with an inexhaustible supply of energy, and is subject to no known law. Now in consequence of the great enlightenment which has resulted from the discovery of radium, and which has followed also upon certain biological investigations made in connection with the study of immunity to infectious diseases, it is highly probable that Darwin's pangenetic theory advanced to account for some of the phenomena of heredity, may after all prove not so untenable as some scientists believe, for we are informed that even the α particle of radium ionises extraneous atoms with which it comes in contact, and charges at the same time some with positive and others with negative electricity.

Regarding the germ cells it is incumbent upon us to remember that much of our knowledge concerning these cells is derived from animals whose reproductive cells meet and coalesce and eventually develop into new organisms outside the animal's body. Now life is impossible without metabolism, but it is very evident that the metabolic state and disposition of a blastomere constructed outside the animal body must be very different to the metabolic inclinations of a blastomere which under ordinary circumstances is not only formed in the material body, but remains therein until fœtal development and growth are completed. Consider even what obtains in the case of the domestic hen. In this animal the egg is fertilised in but hatched outside the mother's body. Here the mere commingling of the sperm with the germ element is not all-sufficient to ensure development and growth, as appears to be the case with the sea-urchin. If, in fact, the energising influence of a constant and well-regulated heat be withheld from the fertilised egg of the barn-door fowl then the metabolic processes distinctive of life are never aroused, and sooner or later in their stead we witness those chemical changes which characterise decay and death. What the energising influences may be which are necessary to arouse metabolism in the fertilised egg of the sea-urchin we know not, but judging from the ease with which in this animal fertilisation can be effected artificially and independently of any spermatic intervention whatever, we may assume that the energising influence cannot be of any great import or significance.

It has been computed that in each ovary of the mature human female fœtus there are not less than thirty or forty thousand ova and it is generally believed that ova continue to form for some time after birth. It is alleged that the law of survival of the fittest is very much in evidence in the ovary and it is suggested that the ova which reach maturity and are fitted for perpetuating the race attain this distinction by devouring their

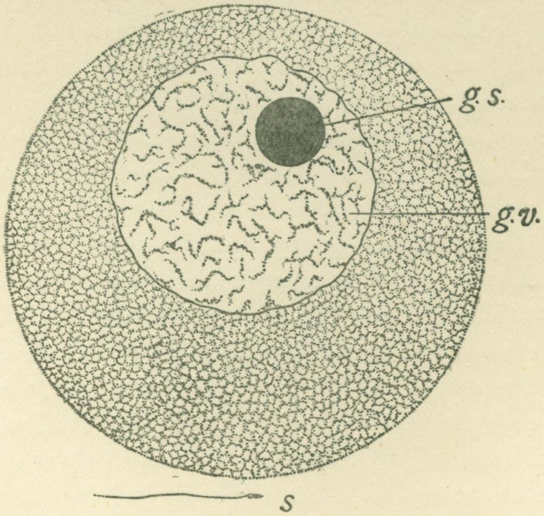


Fig. 4. Ovarian egg of Sea Urchin, *g.s.*, germinal spot; *g.v.*, germinal vesicle; *s.*, spermatozoa—from *The Cell in Development and Inheritance*, by Dr. E. Wilson.[1]

[1] Dr. E. Wilson very kindly gave the author permission to reproduce the illustrations Nos. 4, 5, 6 and 7 from the above mentioned book, published by Messrs. Macmillan & Co.

competitors. Be this as it may, the ripe ovarian cell consists of cytoplasm with a nucleus or germinal vesicle embedded therein, and within the nucleus there is commonly a nucleolus or germinal spot. (See Fig. 4.) The nucleus is supposed to be the all-important structure and is the accredited basis of heredity. It contains a substance distributed throughout it like a fine net and this substance because of its affinity for staining re-agents is known as chromatin. As the egg-cell prepares for division whether for the formation of polar bodies simply or for the formation of segmentation cells, the chromatin substance loses its reticular character and forms a more or less definite number of bodies which assume generally a rod-like shape and these bodies are the so-called chromosomes. In treating of the chromatin material, Wilson says, "the remarkable fact has now been established with high probability that every species of plant or animal has a fixed and characteristic number of chromosomes which regularly recurs in the division of all its cells; and in all forms arising by sexual reproduction the number is even." We learn that man is endowed with sixteen chromosomes but if the number is of any material import it seems more than strange that the ox and the guinea-pig, two animals far removed from each other and from man, should also possess the same number of chromosomes as man.

At or near the time of fertilisation the structures known as polar bodies are formed by mitotic division. (See Fig. 5.) Now Weismann says: "The theory of heredity forces us to suppose that every fertilisation must be preceded by a reduction of the ancestral idioplasms present in the nucleus of the parent germ cell to one half of their former number," and this authority considers that the reduction is effected through the agency of the second polar body. If however such an important duty devolves upon the second polar body it seems most remarkable that it should be a matter of no consequence to subsequent events whether the polar bodies are formed and got rid of before or after the entrance of the spermatozoon. Moreover in parthenogenitic ova the polar bodies behave in no fixed manner but disport themselves differently in the case of different animals. In the Aphides, for example, no reduction in the chromosomes takes place and one polar body

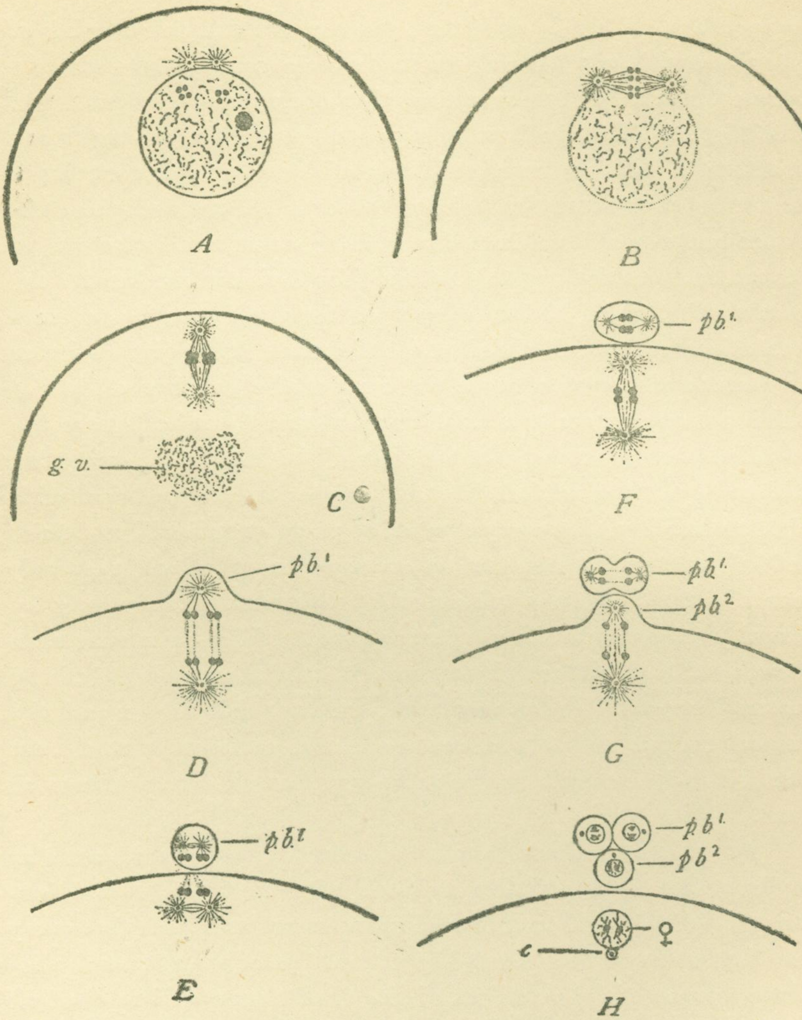


Fig. 5. Diagrams showing the essential facts in the maturation of the egg. The somatic number of Chromosomes is supposed to be four : *p.b.*, Polar Bodies ; *c.*, Chromosomes—from page 237 of *The Cell in Development and Inheritance.*

only is formed, whereas in the Bee two polar bodies are formed in the eggs which produce drones and although these eggs are unfertilised they nevertheless produce functionally active males, males which generate spermatozoa. Again in the Crustacean Artemia, an animal in which males appear very rarely, the parthenogenetic ova may form either one or two polar bodies. When however two are formed the second fulfils apparently some very important function, for instead of being expelled from the egg cell it remains in it and behaves as a sperm nucleus would. Regarding the function of the first polar body, Weismann considers that it removes half the total mass of the chromatin material and carries therewith the ovogenetic substance. From a careful scrutiny of facts, however, it is very evident that we as yet know nothing definite regarding the functions of either the one or the other polar body, but whatever their functions may be they are as a rule formed more or less rapidly one after the other in the upper or animal pole of the ovum, and as in the majority of instances the egg-cell seems thereafter to have no further need of them they perish forthwith.

The spermatozoon for obvious reasons was discovered and studied long before the egg-cell, but we really know much less about it than the ovum. Its configuration is not the same in all animals, and some animals for no apparent reason are endowed with two different kinds of spermatozoa. For descriptive purposes we may take the human spermatozoon. (See Fig. 4.) It consists of a head, a middle piece, and a tail. The head is crowned with an apical body and from tip to tail the spermatozoon measures about the one-five-hundredth part of an inch. The tail, which comparatively speaking is of enormous length—four-fifths the length of the entire animalcule—is purely and simply an organ of locomotion, and by the lashing movements of this appendage the spermatozoon is enabled to make its way to and effect a union with the more or less inactive egg-cell. The head, which constitutes the nucleus, is crammed with chromatin, and it is this portion together with the middle piece in which is lodged the material for the formation of the cleavage centrosome, which are the structures immediately concerned in the fertilisation process. Within the ovum the sperm nucleus rapidly increases in size. Normally only one spermatozoon enters and unites with the egg-cell and as the latter in the human female cannot possibly evade approaching spermatozoa it is truly astounding that so many millions should be required to ensure that one spermatozoon may if possible fulfil its function. In treating of spermatozoa Weismann says: "the smaller the chances of any single sperm-cell being successful the larger the number of such

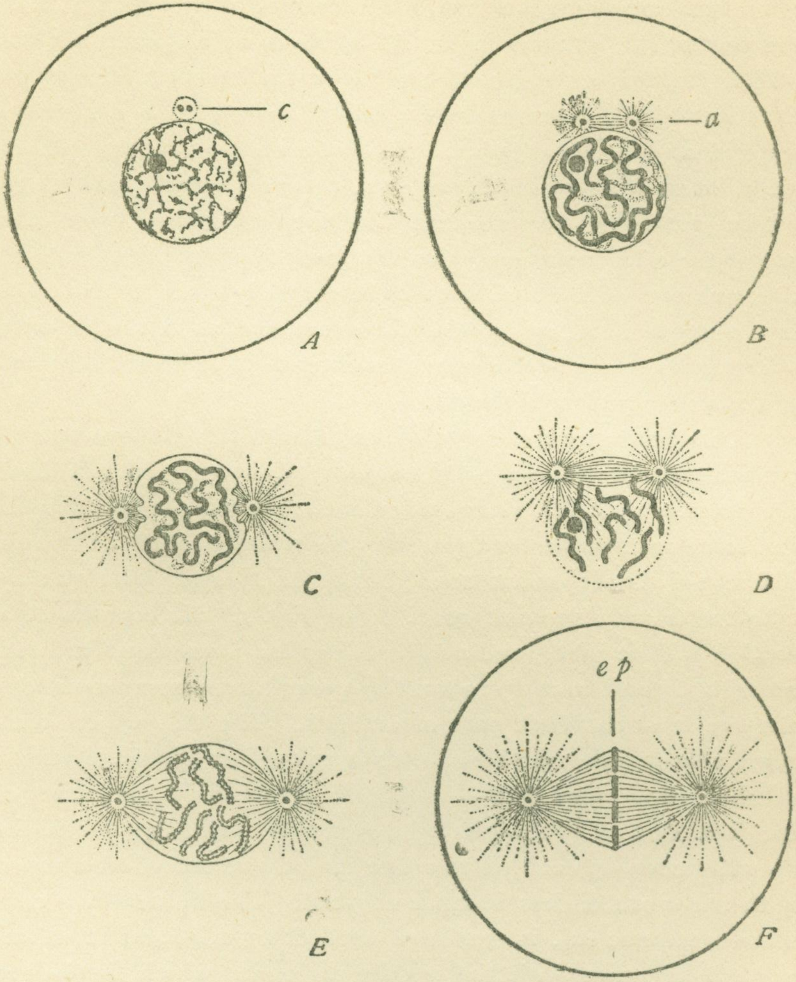


Fig. 6. Diagrams showing the prophases of mitosis, *a*, Amphiaster, *C*, Centrosome, *e.p.*, equitorial plate—from page 66 of *The Cell in Development and Inheritance.*

cells produced and the direct result of this increase in number is a diminution in size." As applied to man it is quite clear that such a declaration is meaningless. If each spermatazoon were functionally active and every ovum extruded from the ovary were fit for fertilisation it is impossible to imagine how any advantageously circumstanced ovum ever escapes, and yet the great majority avoid fertilisation. Contrast this state of affairs with what obtains in the domestic hen. In this animal the male at one stroke very commonly effects the fertilisation of twelve or even fifteen egg-cells, and although many of these must at the time of fertilisation have been in an immature state still the greater number will if befittingly incubated produce healthy chicks. It furthermore is most noteworthy that although the last egg laid of such a batch was subjected after fecundation to a steady and well-regulated heat in the mother's body for twelve or it may be fifteen days longer than the first egg laid, yet these two eggs respectively require to be incubated for exactly the same number of days—*viz.*, twenty-one—outside the mother's body before the chick is hatched. Now it is facts like these and others of an equally astounding and inexplicable nature which should make us guard against framing conclusions regarding some important reproductive phenomena in man based simply and solely upon the results obtained by experimenting upon animals low in the scale of life.

Before developmental changes can proceed in the egg-cell of at least the majority of the higher animals a spermatozoon must have penetrated into it, and by the union of the sperm with the germ nucleus a segmentation nucleus must have been formed. At this time, the nuclear membrane having disappeared, the nucleus, which is now composed of chromosomes derived equally from the two parents, assumes the form of a spindle, and thereafter the cell proceeds to divide, the process of division being dominated by the centrosome. (See Figs. 6 and 7.) This cleavage centrosome, which is a male structure present in the middle piece of the spermatozoon, divides in the first instance into two portions. These two portions diverge to opposite poles of the segmentation nucleus, and speedily thereafter the egg-cell splits into two apparently equal cells called blastomeres, and it is these first two segmentation cells which, when opportunely endowed, furnish us with identical twins.

Within recent years Herbst, Driesch, Loeb and others have demonstrated not only that enucleated eggs and fragments of eggs can be fertilised by spermatozoa, but also that without the intervention of any spermatic material at all, eggs may be fertilised quite artificially by physico-chemical influences alone. They have even shown that living larvæ can be obtained in the case of sea-urchins, star-fishes, and some annelids as well as

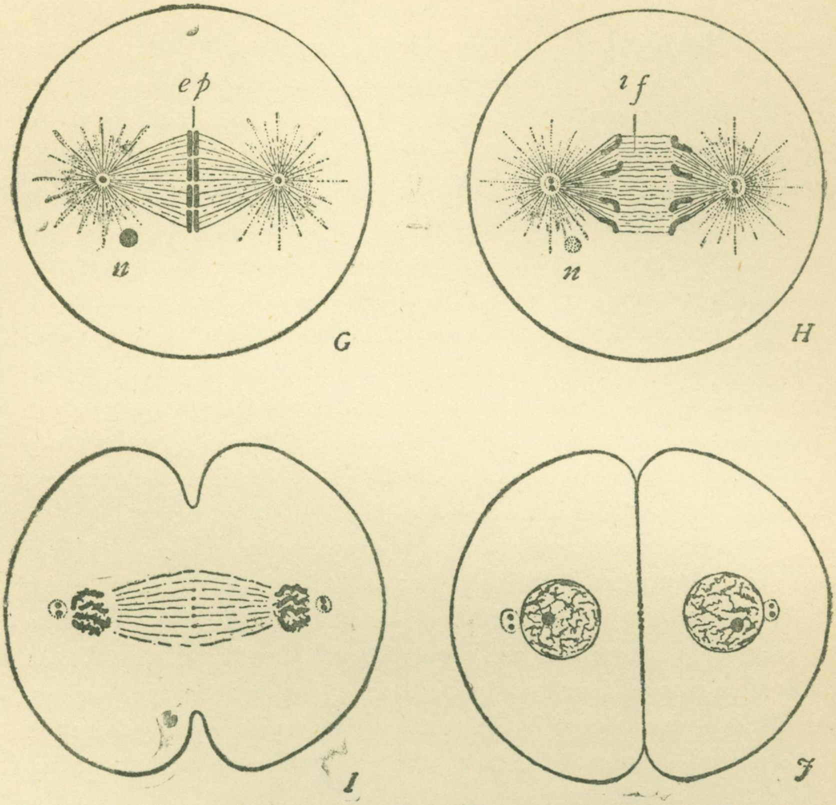


Fig. 7. Diagrams of the later phases of mitosis—from *The Cell in Development and Inheritance*.

molluscs, simply and solely by the action of inorganic re-agents upon the unfertilised eggs of these animals. In endeavouring, however, to appraise at their true value the results of such experiments it is well for us to remember that the unfertilised eggs of some animals—possibly a larger number than we are aware of—which are not expected to develop unless fertilised, may nevertheless undergo segmentation and attempt to produce new organisms, in spite of the fact that they have not been subjected to the influence of any extraneous material at all. The unfertilised eggs of the silk moth Bombyx Mori not infrequently behave in this manner, but it may be noted that although such eggs reach various stages of development, they always abort eventually, and none so far has been known to produce a new organism.

We have already observed that the nucleus of the germ cell is believed to play an important *rôle* in heredity as well as in the nutritive phenomena of the cell generally. On these points, however, the evidence provided by experiments upon mutilated eggs is far from conclusive or satisfactory. Delage, for instance, informs us that under the microscope he has divided the minute egg-cell of the sea-urchin in such a manner that one portion contained the entire nucleus, whilst the other portion possessed no nuclear material at all. He thereupon exposed these two mutilated portions in company with a normal ovum to the influence of sea-urchin spermatozoa, and strange to say, all three egg-cell structures attracted spermatozoa equally well. All three became fertilised, and all three produced living organisms. In spite, however, of the fact that one of these embryos was developed from an egg-structure possessing no nuclear material at all, Delage nevertheless, found nuclei of apparently the same constitution, and with the same number of chromosomes in the somatic cells of all three embryos. Again, some observers have fertilised enucleated eggs of the Echinus micro-tuberculatus by spermatozoa of a totally different species, and obtained thereby larvæ which displayed paternal characteristics only, whilst Godlewski, on the other hand, states that he has fertilised enucleated eggs of the sea-urchin by spermatozoa of a Crinoid (sea lily), and obtained thus larvæ which exhibited no paternal, but solely maternal characteristics. In spite, however, of such experimental discrepancies, we nevertheless from our intimate knowledge of the modes of multiplication in the protozoa are fully justified in believing that every organism begotten of two parents receives the total potentialities of both, including even a bisexual equipment from each, but that characteristics may be inhibited or accentuated in the offspring by the reciprocal action and reaction of imparted parental influences.